Enhanced Structure Path Analysis: A New Method to Create Spatiotemporally Defined Life Cycle Inventory

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1. Introduction

Refinements to the Life Cycle Assessment (LCA) methodology are required to obtain realistic and scientifically sound LCA results. We propose to contribute to this goal with the creation of spatiotemporally defined Life Cycle Inventory (LCI).

A fully spatiotemporally defined LCI will ultimately enable its comparison with extractions/emissions (identified as Pressures in the DPSIR framework) from direct environmental analysis models like GAINS [1] or MESSAGE [2]. It then might be possible to validate the LCI through a comparison with real world observations of substances concentration in the environment.

A spatiotemporally defined LCI is also needed to enhance the environmental impacts analysis and their optimization. Recent studies have shown that some environmental impact factors would require to be geo-dependently defined [3] and to be of use, the methodology requires a spatiotemporally defined LCI. Spatially defined LCI will also be useful to identify the sites of resources depletion and high pressures on certain environment created by abundant emissions. Temporally defined LCI will allow the identification of extractions/emissions which have already happened over the life cycle of the system at the time of the analysis. This information is necessary in order to identify future abatement potential of scenarios.

2. State of the art in spatially defined LCA

One method has been proposed to create spatially resolved LCA results [4]. This method uses a modified standard LCA calculation. Equation 1 presents this calculation where $\boldsymbol{R}$ are the geo-localized impacts, $\boldsymbol{G}$ is the matrix defining the spatially specific impact factors, $\boldsymbol{E}$ the environmental exchange matrix, $\boldsymbol{T}$ the technological exchange matrix and P the vector defining the analyzed processes.

$$\boldsymbol{R} = [\boldsymbol{G} \circ \boldsymbol{E}]diag(\boldsymbol{T}^{-1}P) \quad (1)$$

The main difference between the standard LCA calculation and this method (which we will call: Mutel's method) is the number of processes needed to define the $\boldsymbol{G}$ matrix. Mutel's Method requires new rows and columns for each site of emission even if the technological processes are identical. This means that the size of the vector and matrixes of equation (1) will grow quite rapidly when the analyzed scenario requires many processes at different locations over its supply chain. It also means that we need to create new $\boldsymbol{E}$, $\boldsymbol{T}$ matrixes and P vector for each spatially resolved impact assessment method. This growth in size will be even more important if we want to create a temporally defined LCI.

3. Proposed methodology to obtain spatiotemporally resolved LCI

Our hypothesis is that we should use a calculation method where we can identify the links between technological processes in the supply chain in order to be able to use functions to integrate temporal information within $\boldsymbol{E}$ and $\boldsymbol{T}$ matrixes. We then could obtain a spatiotemporally defined LCI to which we could apply any impact analysis method if translated accordingly. To our knowledge, the only way to identify the links of a supply chain is to use the Structure Path Analysis (SPA) methodology [5].

3.1. Calculation method

We call this new method the ESPA (Enhanced Structure Path Analysis) method. ESPA creates LCI where each extraction/emission is spatiotemporally characterized. The ESPA calculation is defined by equation 2.

$$Inventory(x, y, t) = (\boldsymbol{E}_0 + \boldsymbol{E}_1\boldsymbol{T}_1 + \boldsymbol{E}_2\boldsymbol{T}_2\boldsymbol{T}_1 + \boldsymbol{E}_3\boldsymbol{T}_3\boldsymbol{T}_2\boldsymbol{T}_1 + \cdots)P \quad (2)$$

Figure 1 represents, through an example, a supply chain linked to Process 1 along different levels and explains critical information that needs to be defined in each matrix and vector. Here, the database informs on the location and time of each process and sub-processes. Therefore the definition of one process can only be linked to one location. We also define the time for each extraction/emission inside each process. Temporal functions will be used both for describing the links between processes and the moment of extraction/emission. By modeling time information as functions, we can use temporally defined processes for many studies without changing each time their temporal information.

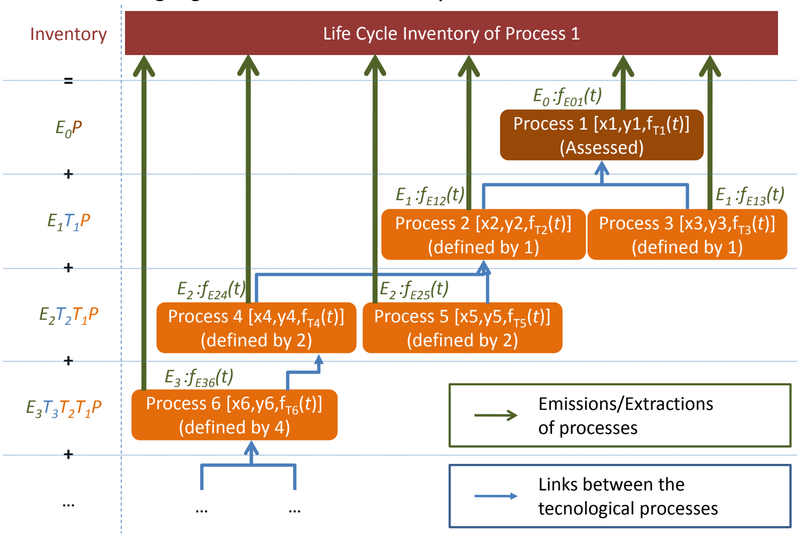

Figure 1 : Schematics explaining the spatial and temporal characterization at the different steps of the ESPA calculation.

There is a need to fix a level at which the series' calculation will be stopped. Previous research [6] have identified that most environmental impacts will be accounted for in between the first and twenty fifth levels for most scenarios in the ecoinvent database [7]. And so, for now, we choose the first 25th levels as a limit of the calculation.

The ESPA inventory results will follow a generic format allowing to be translated into different geographical coverage so that it can be used by any spatially and/or temporally resolved impact assessment method.

3.2. Database definition requirements

We address the definition of time functions for which we call the processes and time functions for the moment of extractions/emissions in the database structure. The use of functions can only be applied with the ESPA method and not with Mutel's method. Time functions are required for the representation of continuous extractions/emissions over time. The ESPA method can be used with varying precision on the definition of time and location.

4. Conclusions

We describe a new way of calculating spatiatemporally defined LCI which is based on the SPA methodology. This new ESPA method is a first step to create LCA results which should be more realistic and which might be compared in the future to real world observations first at Pressure level and then at State level by using appropriate models.

5. References

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